Interference Estimation for Multiuser Systems

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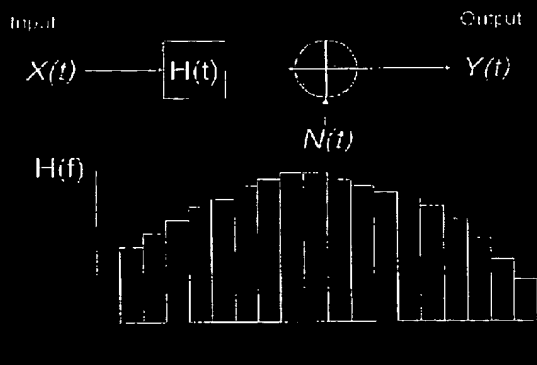
Outline

- Aggregate Interference
- Interference Coupling Functions for Multiuser Detection
  - Block
  - Recursive
- Conclusions

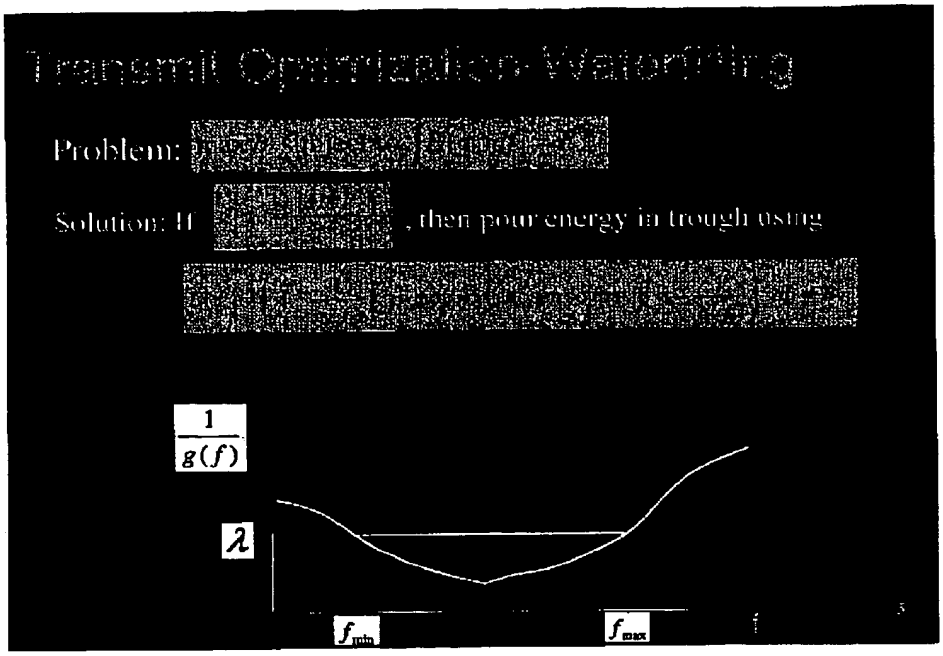
Motivation for Detecting Aggregate Interference

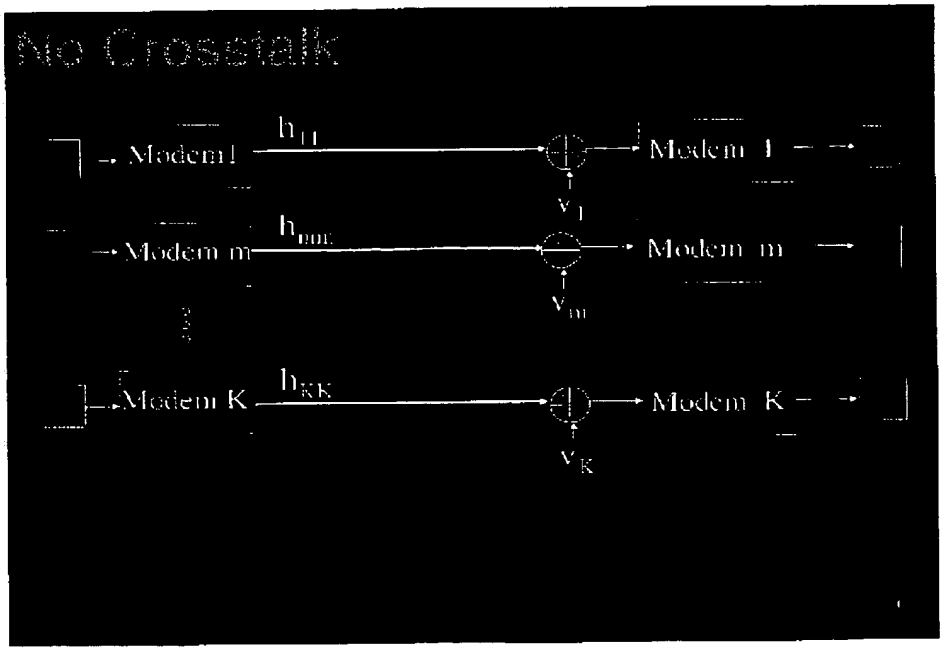
- Transmitter Optimization
  - Increase data rate and/or line reach
  - Reduce power consumption
- Track the changing environment conditions
  - React faster
  - Prevent modem retraining

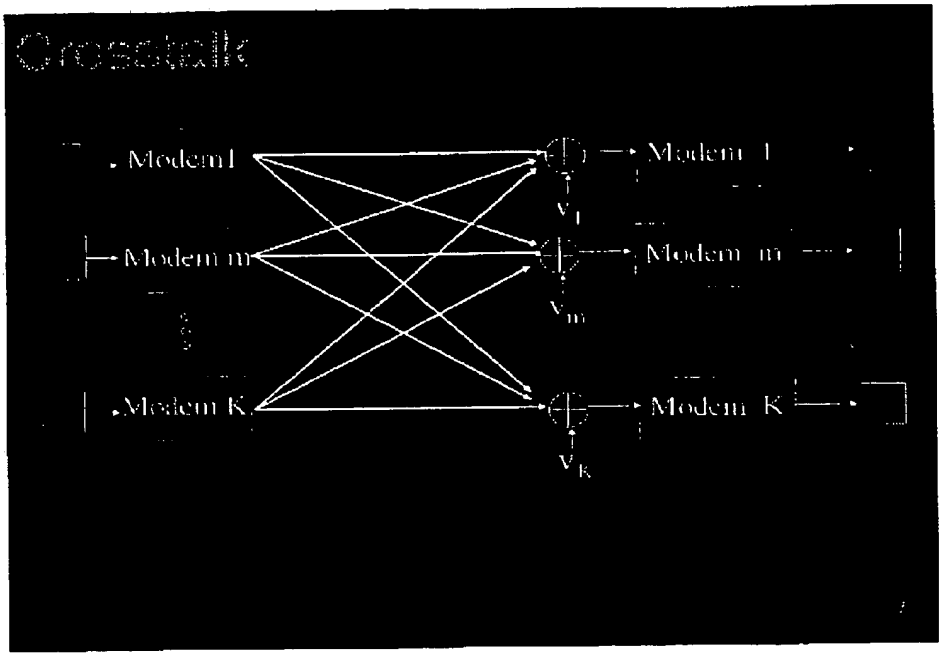
Multicarrier Transmission

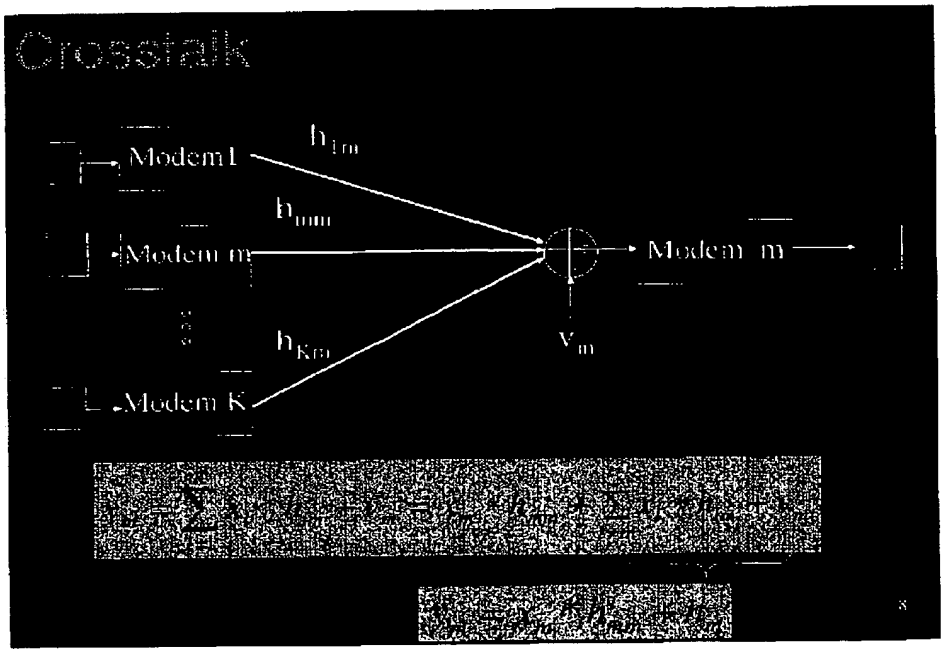


- Modulation done in frequency domain
- Transmit signal is IDFT of subchannel symbols
- Robust to frequency selective environments

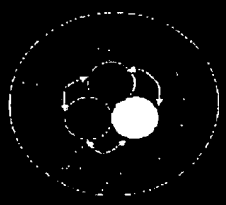








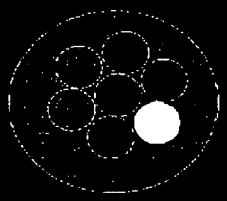
The Main Technology Issue



Cross-section of cable

- Crosstalk – interference between lines
  Largest source of impairment and performance loss

Profile 1

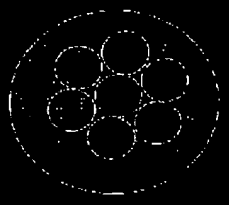


Cross-section of cable

RED=OFF
ISDN ON
ADSL ON
HDSL ON

Profile: State determined by the number and the kind of crosstalkers present.

Profile 2

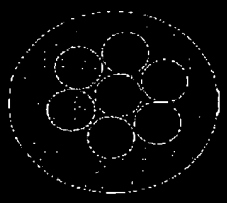


Cross-section of cable

RED=OFF
ISDN ON
ADSL OFF
HDSL ON

Profile: State determined by the number and the kind of crosstalkers present.

Profile 3

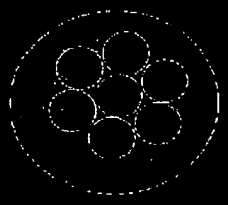


Cross-section of cable

RED=OFF
ISDN ON
ADSL OFF
HDSL ON
T1 ON

Profile: State determined by the number and the kind of crosstalkers present.

Profile 4



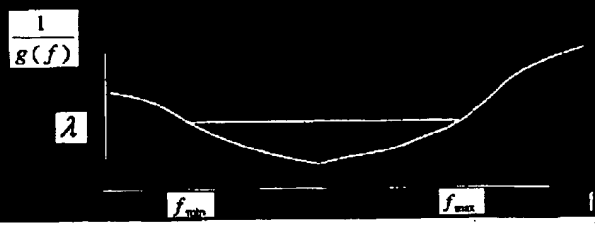
Cross-section of cable

RED-OFF
ISDN ON
ADSL OFF
HDSL ON
T1 ON
G. LITE ON

Profile: State determined by the number and the kind of crosstalkers present.

Profile

- Use profiles to track changing crosstalk conditions.
- Noise measurements matched to a set of profiles.
- Each profile has an optimized bit and energy table associated with it.



Crosstalk Environments

- NEXT and FEXT (Near-End and Far-End Crosstalk)
- Different services, e.g, HDSL, ADSL, ISDN

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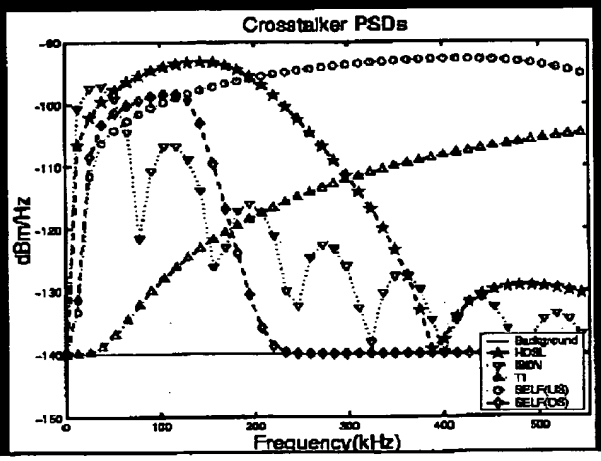
NEXT Crosstalk Example



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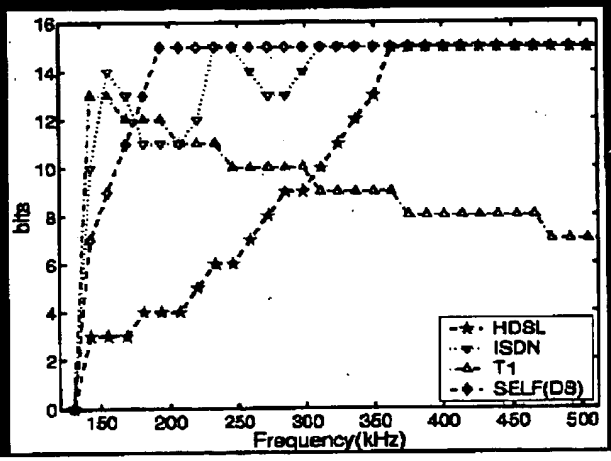
Bit Tables Example for Downstream (DS)

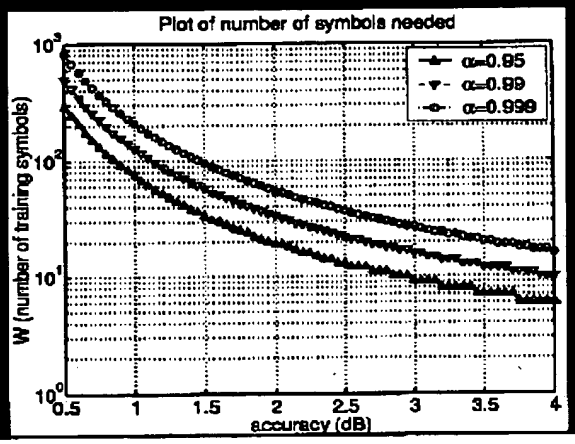


Acquiring a Profile

- Assume block stationarity
- For each tone i, estimate the crosstalk variance over a window of length W:

Number of Symbols Needed

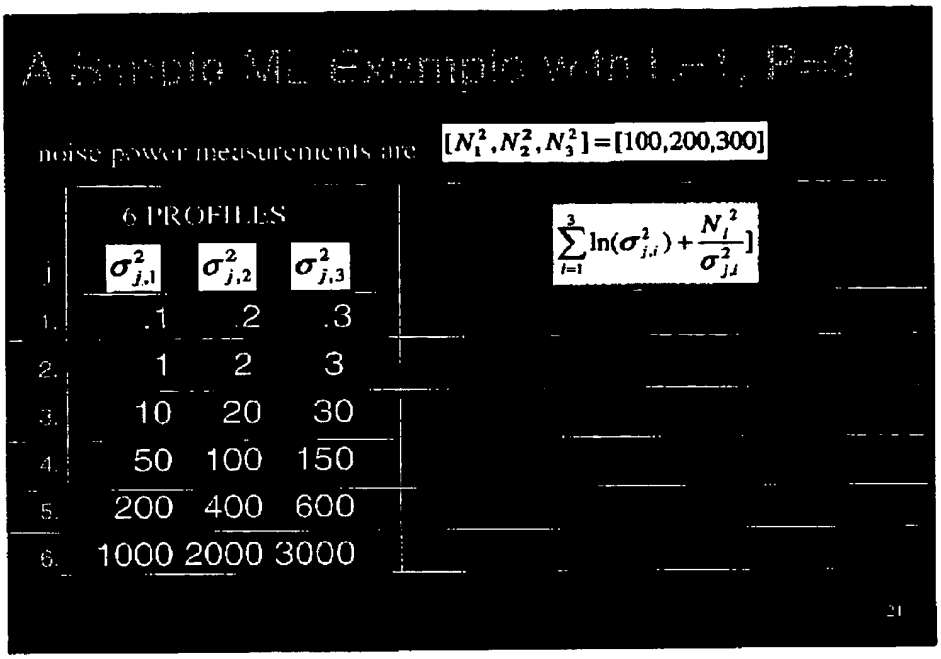
Find smallest W such that:

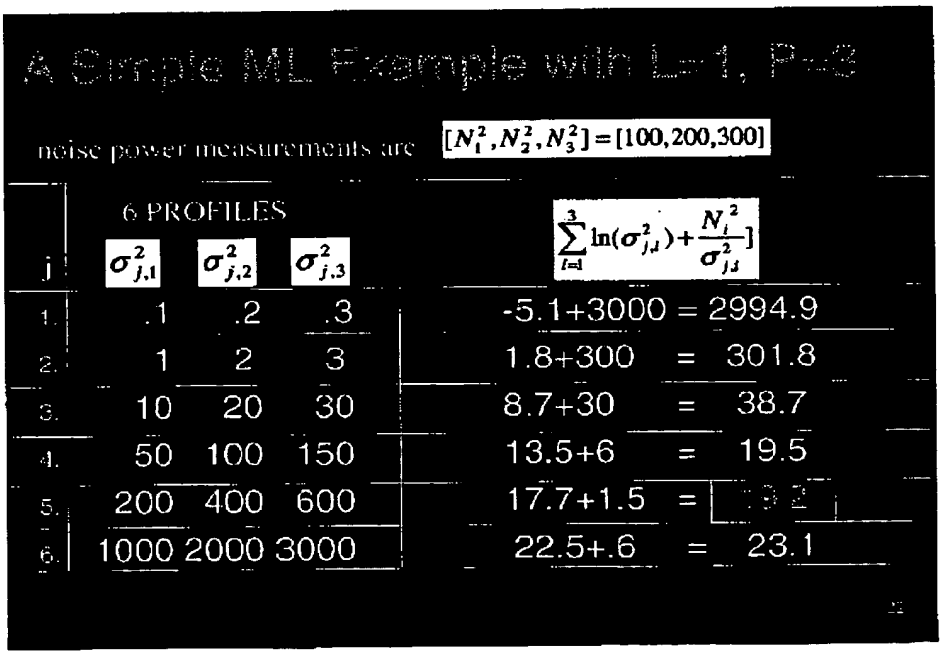


MAP Profile Detection

- Given a set of stored noise profiles, , minimize the probability of choosing an incorrect profile.
- Choose the profile that maximizes the a posteriori probability , where has Gaussian pdf.
- Assuming a window of L multicarrier symbols, MAP algorithm becomes

where

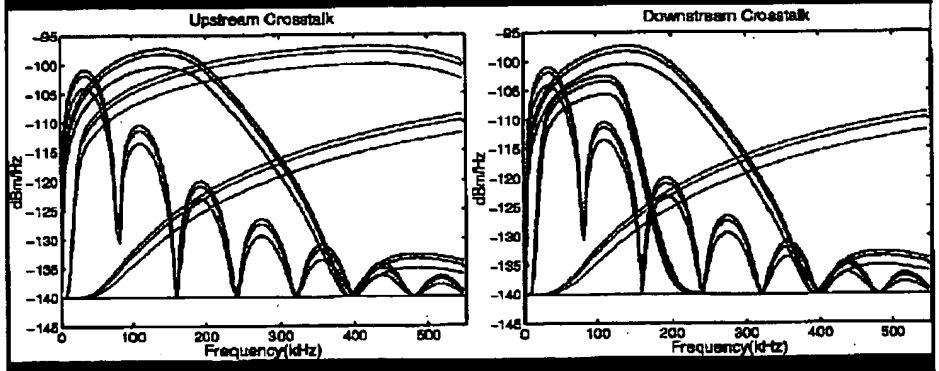




Simulation Setting- ADSL (G.lite)

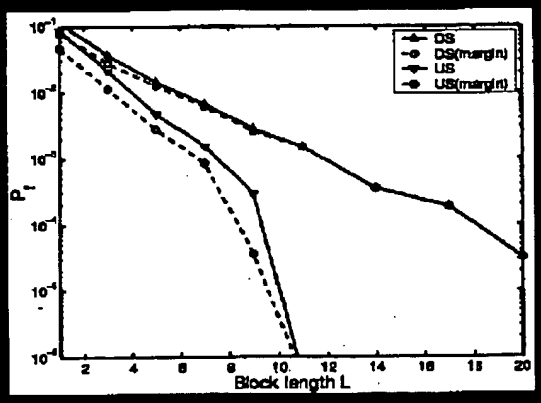
- 128 subchannels (32 for US, 96 for DS)
- Symbol period T=250 us
- 13 profiles for both upstream and downstream stored
  - 3 ISDN (3, 7, 10 users)
  - 3 HDSL (3, 7, 10 users)
  - 3 T1 (3, 7, 10 users)
  - 3 EC ADSL using G.lite (3,7,10 users)
  - Background Noise (-140dBm/Hz)

Profiles Used in Simulation



Simulation Results

- Probability of choosing an incorrect profile
- Probability of the chosen bit and energy table not meeting margin



- For this scenario, use of profiles allows for doubling of the data rate.

Advantages of Profiles

- Increase bit rates by having more profiles
  - Can have fast access to crosstalker activity—no need to transmit to worst case noise scenario
- Prevent modem failure by increasing block length L
- Low complexity

R is no. of profiles, T is the symbol period, P is number of tones.

When R=16, L=20, P=128, complexity = 2.3 MIPS

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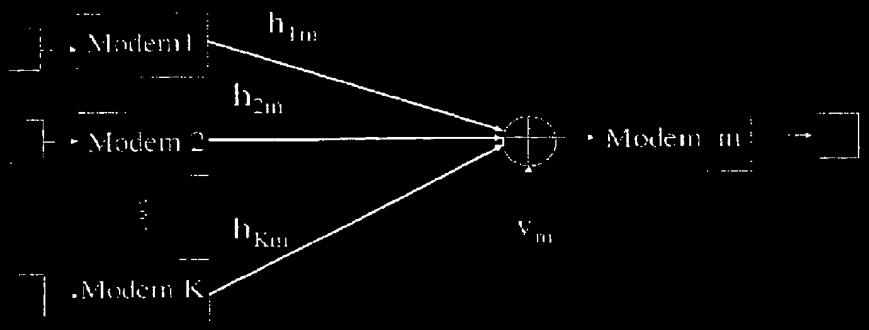
Crosstalk



Goal: Find h_{km}

Motivation

- Multiuser Channel ID
  - Reliable channel and/or noise variance estimates for multiuser detection
  - Maintenance and diagnosis
  - Bandwidth efficient transmission
  - Desire to track the changing environment conditions
  - Estimates can be used for optimizing the transmitter
- Expectation Maximization (EM)
  - Reduce training overhead to practically 0

Previous Work on Channel Estimation

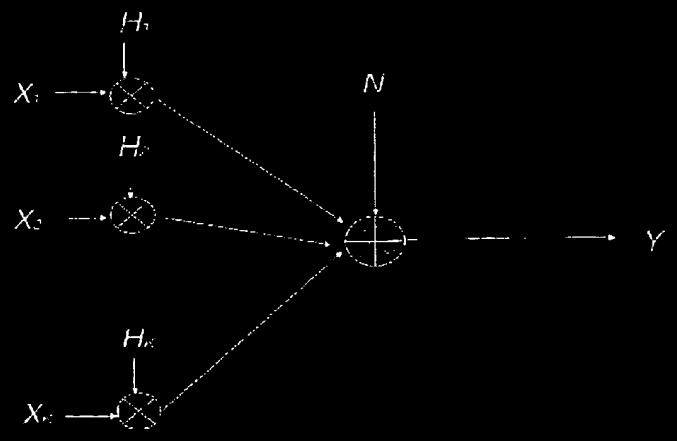
- EM
  - Introduced (Dempster, Laird, 77)
  - SAGE (Fessler, Hero, 94)
  - SISO (Kaleh, Vallet, 94)
  - Recursive SISO (Zamiri-Jafarian, 97)
- MISO
  - Gaussian inputs (Feder, Weinstein, 88)
  - CDMA system (Bhashyam, Aazhang, 00)
- Finite Alphabet
  - MIMO system (Talwar, 96)
  - SISO OFDM (Zhou, Giannakis, 01)

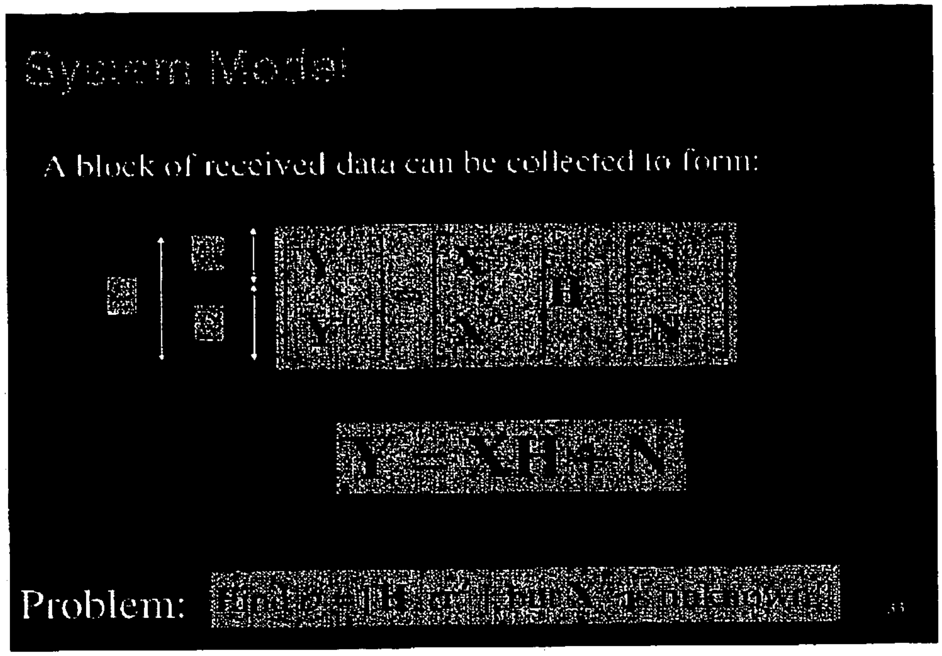
System Model

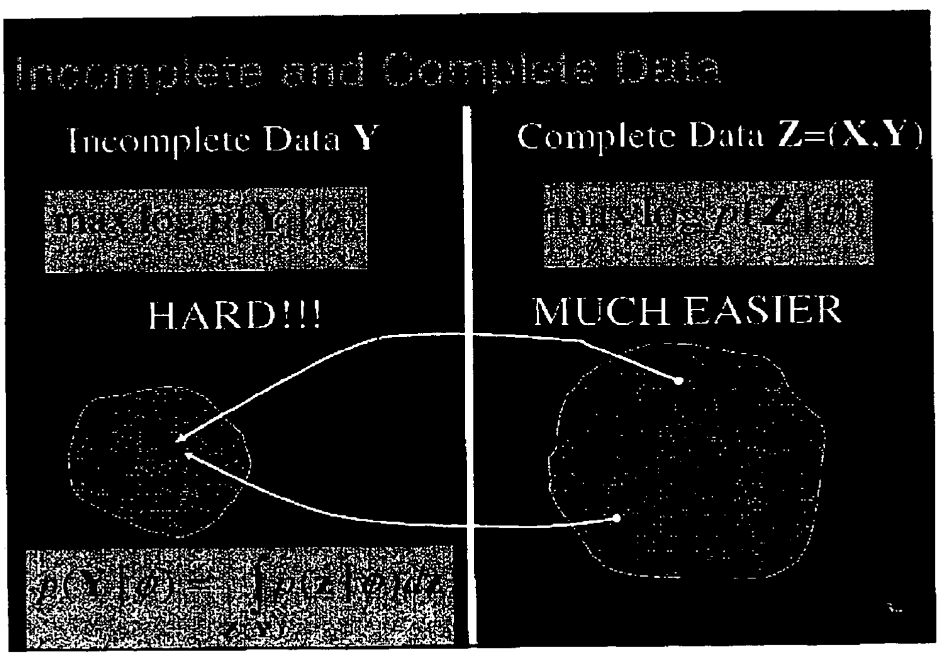
- Multiple access channel: K inputs, 1 output
- Modems are synchronized with same symbol period T
- Receiver knows the constellations of the transmitters.
- Channel and noise are block stationary

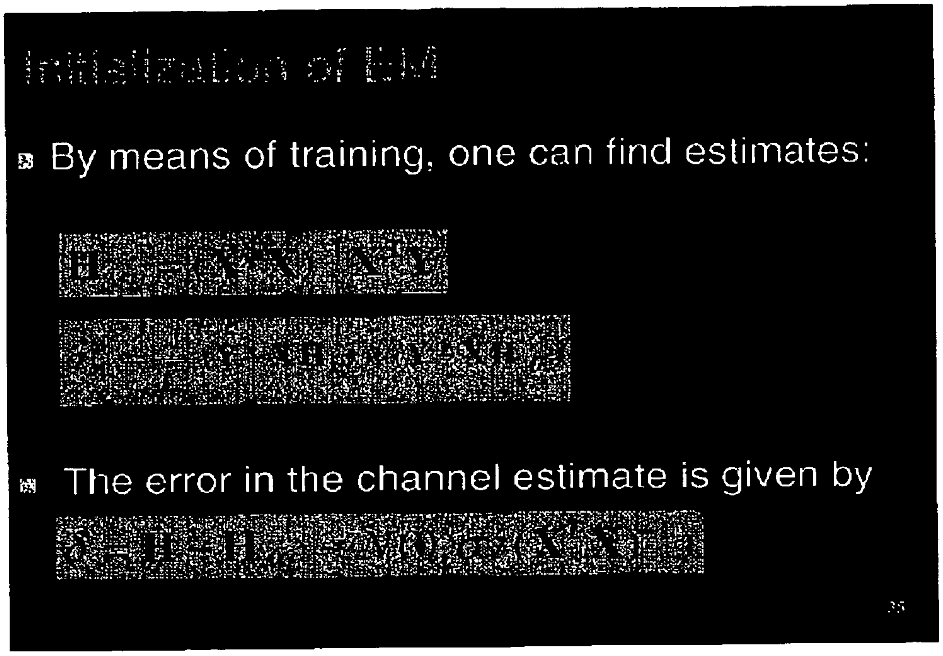
System Model with K Tx's

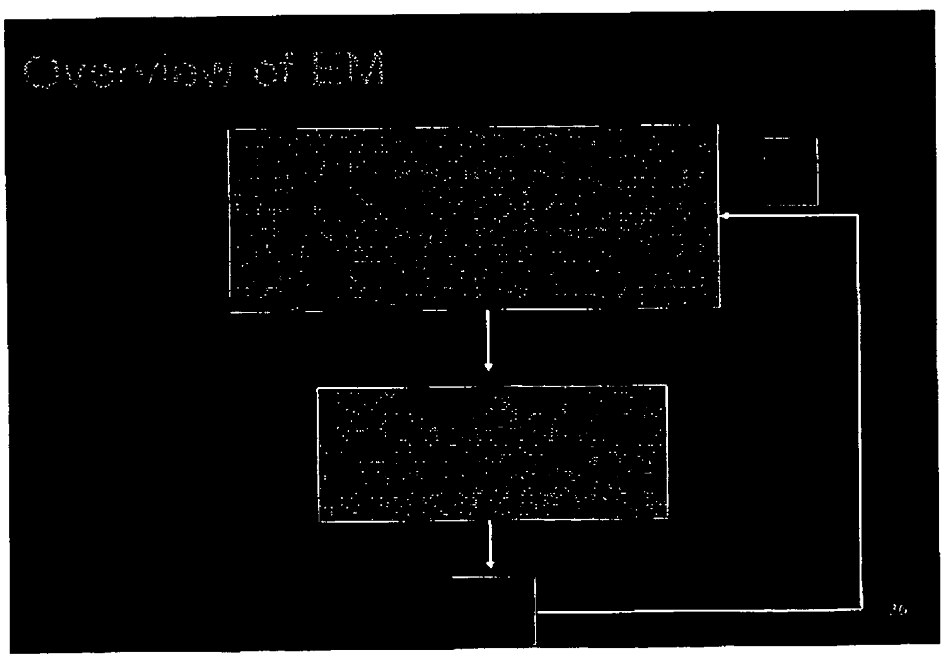
In multicarrier systems with K users, each subchannel appears











ML versus EM Channel Estimation

- ML

Complexity

- EM (iterative)

1. Expectation

2. Maximization

3. Go back to 1

Complexity

Block EM Channel Estimation

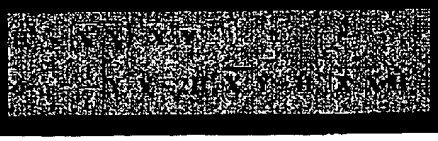
1. Compute

using

2. Compute

in a similar fashion.

3. Channel and noise variance estimates are given by



Advantages of LM

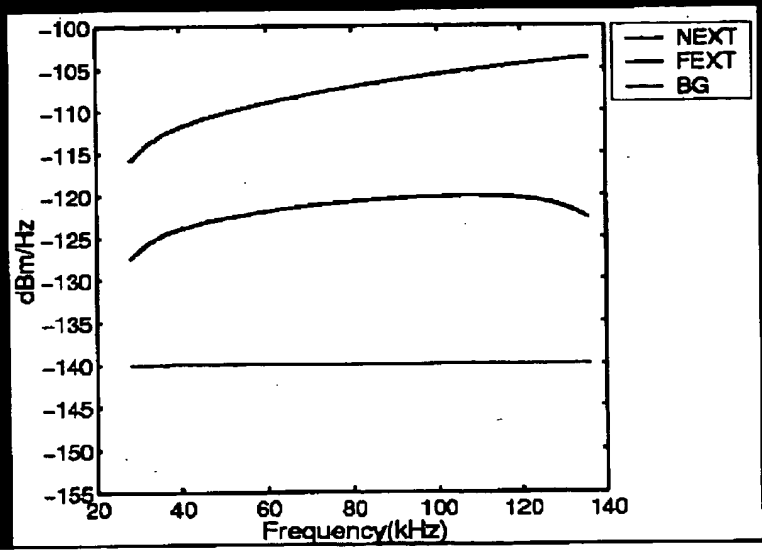
- Takes advantage of finite alphabet property of transmit signal.
- Increases likelihood at every iteration and guaranteed to converge.
- Provides MMSE estimate of transmit data.

Let's take a trip to Japan

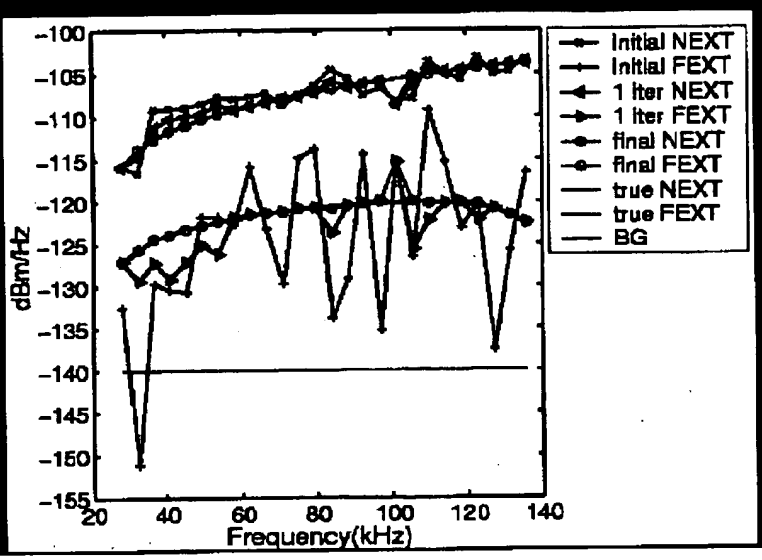
Simulation Setup

- ADSL-DBM modem
  - 1 NEXT (SSDSL) and
  - 1 FEXT (ADSL)
- 500 m line FEXT source
- Initial condition acquired from previous block
- 10 ms of data (Ltr=0, L=40)

EBM Simulation Results



EM Simulation Results



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- Aggregate Interference
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Motivation

- Eliminates delay
- Reduces storage
- Track time-variant parameters in an adaptive manner
- Block stationary assumption no longer needed

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MISO Recursive EM

1. Find [redacted] and [redacted]
2. Compute [redacted]
3. Update

[redacted]

Complexity [redacted]

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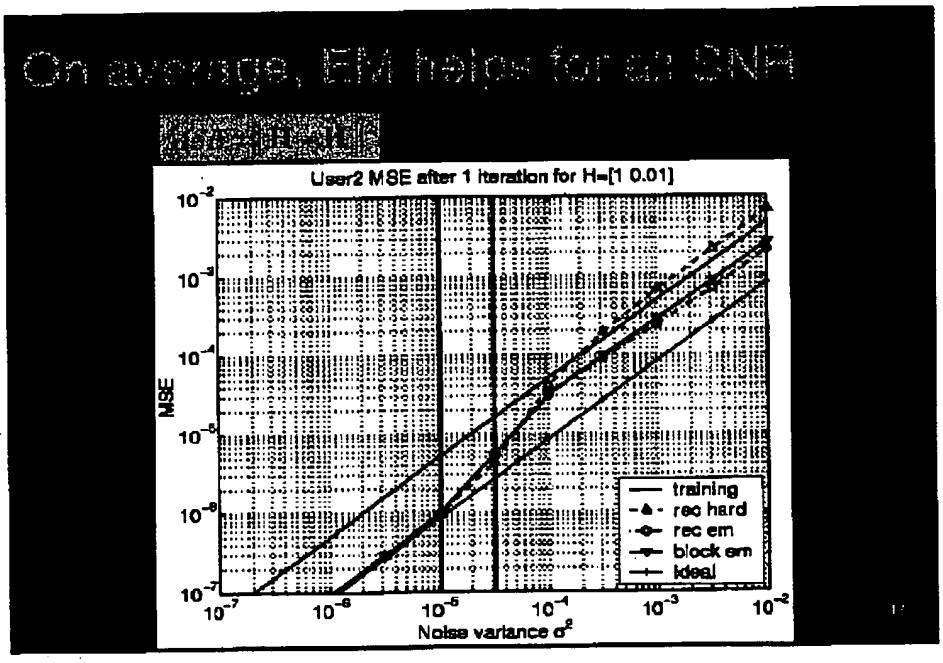
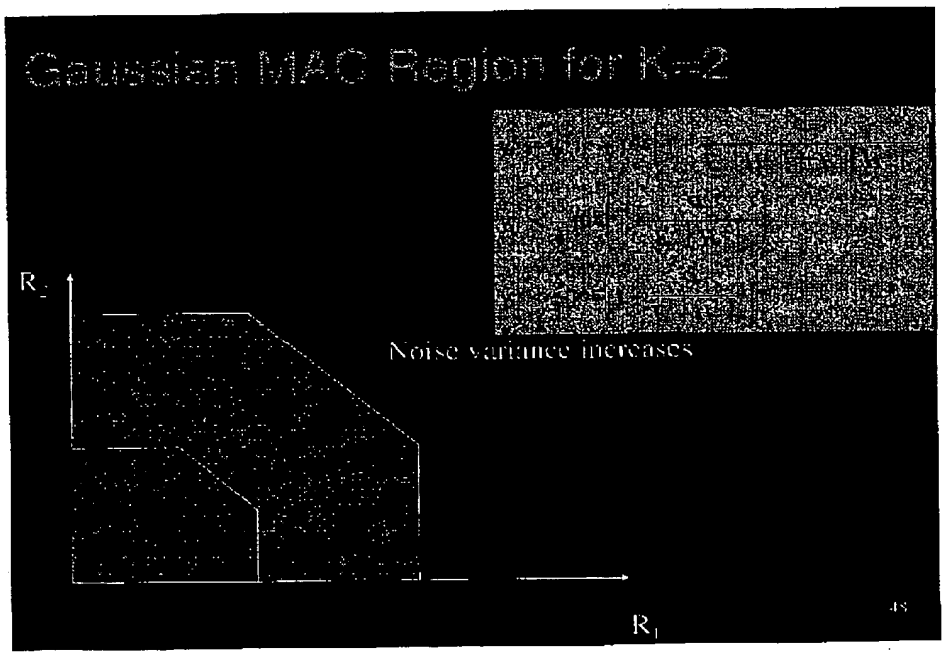
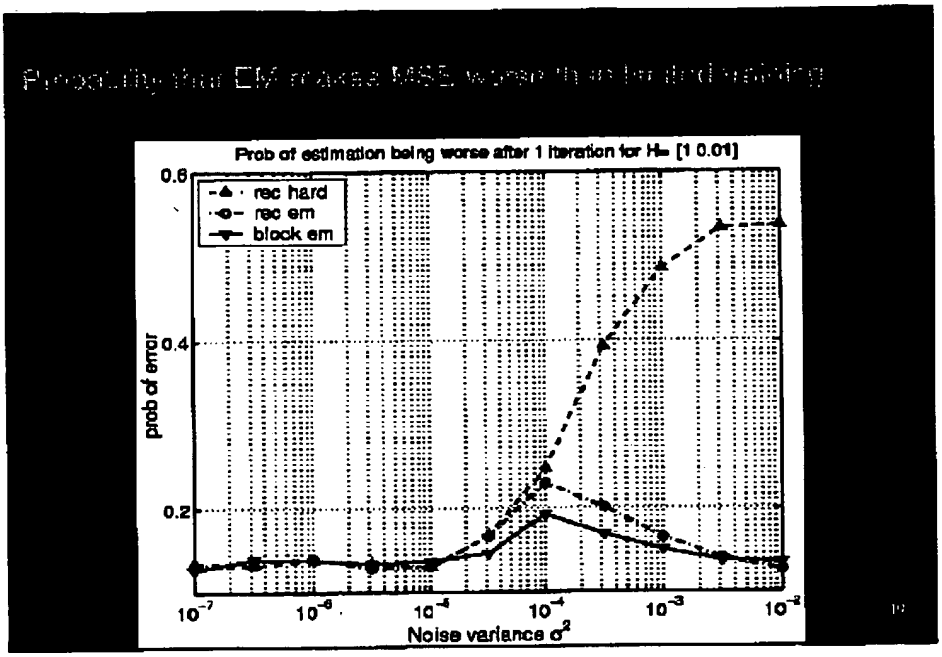




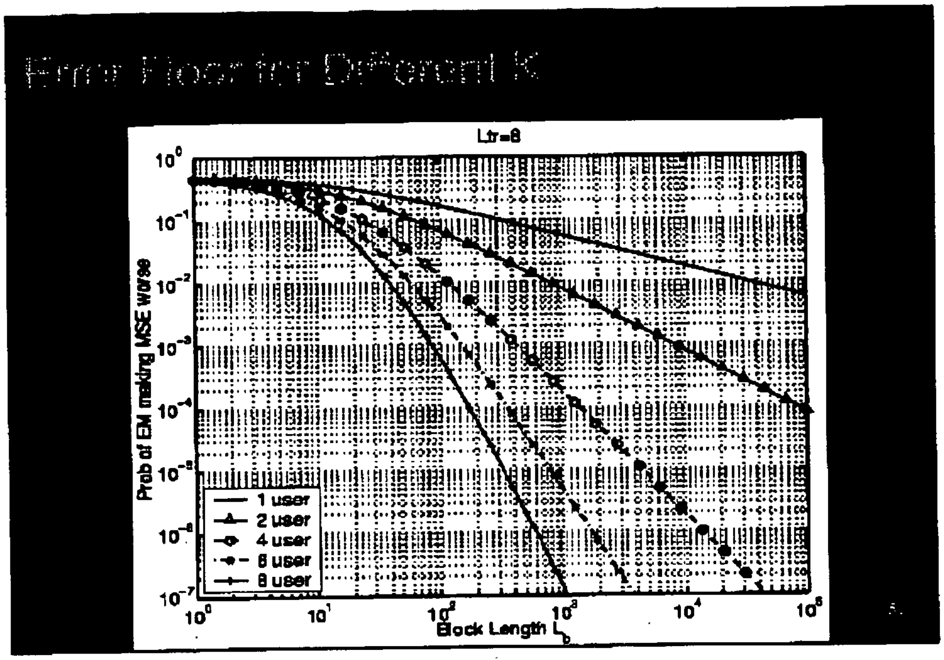


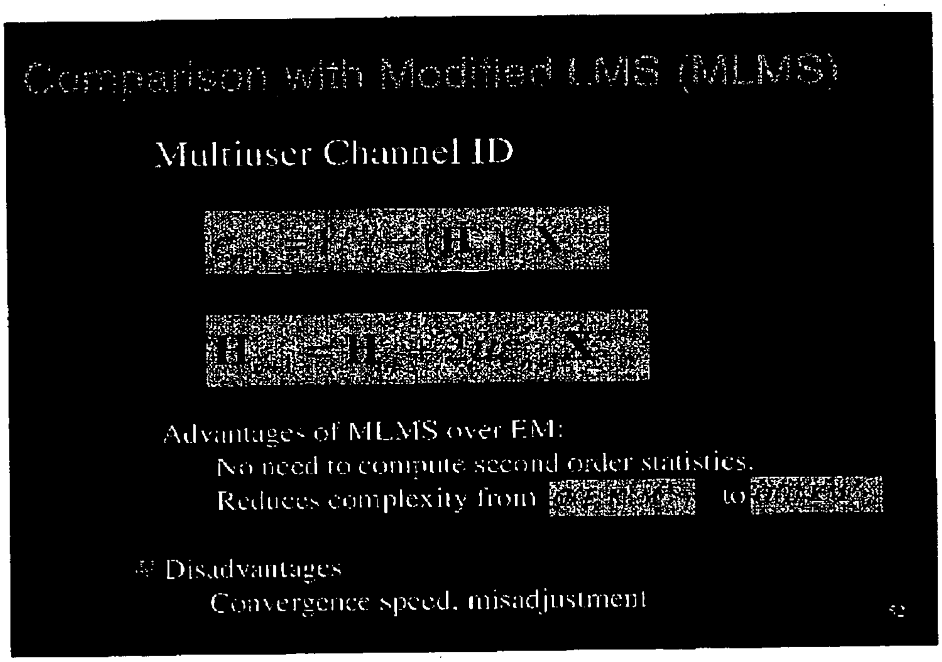
Error Floor Analysis for EM w/ training

If each user has equal energy , and we assume that

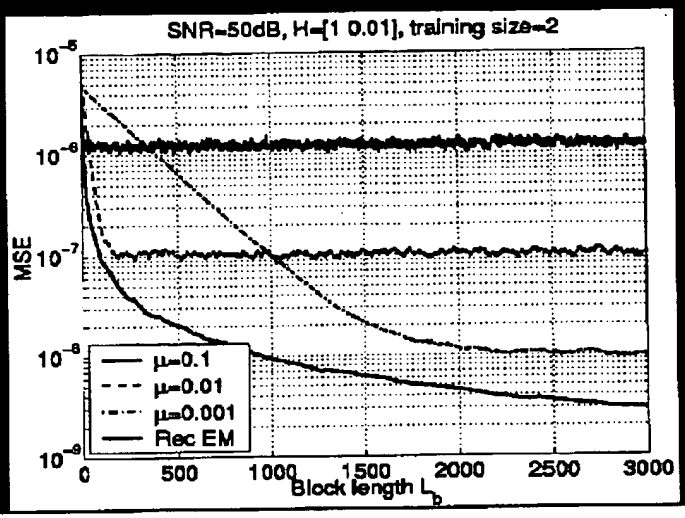
- [redacted]
- Training portion and training+blind are independent then:

[redacted]





MIMO versus Recursive EM inside MAC



Summary of Contributions

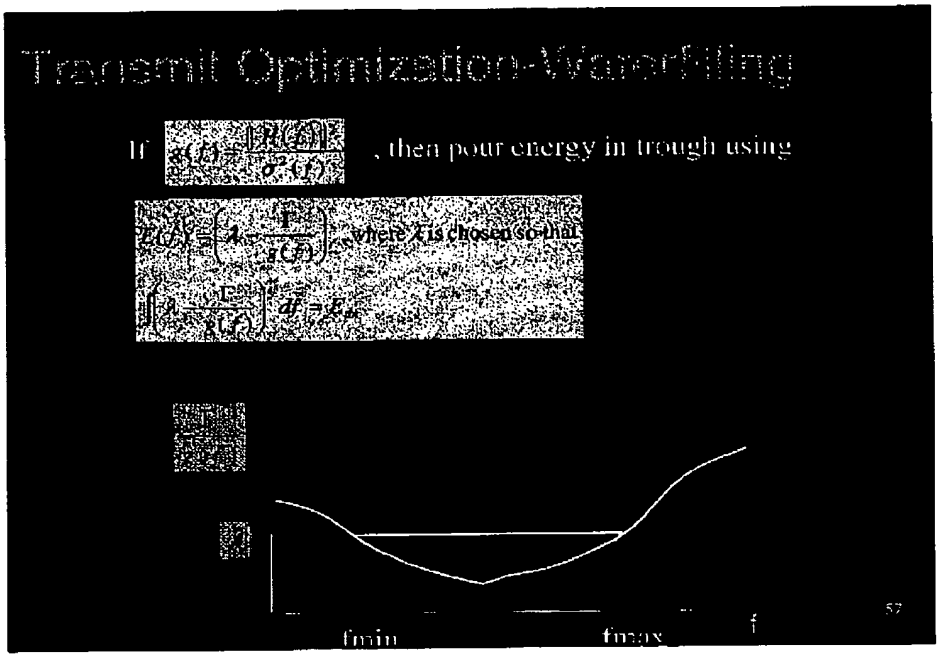
- Identified crosstalk spectrum using accurate and low complexity algorithm
  - Higher data rates
  - 4s Profile 5ms
- Obtained multiuser ML channel and noise estimates
  - Soft decisions better than hard decisions
  - Improved training estimates outside the MAC region
- Developed recursive solution
  - Less storage and delay
- Additional work
  - Extension to MIMO systems
  - Application to coded systems

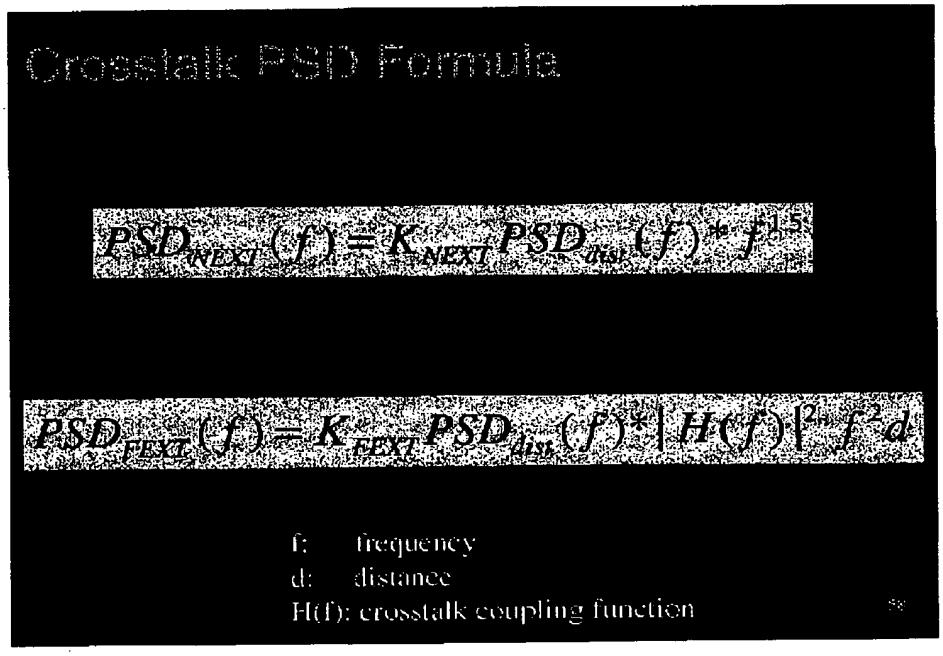
Papers

- Aldana, Carvalho, Cioffi, "Channel Estimation for Multicarrier Multiple Input, Single Output Systems using the EM Algorithm", to be submitted to Trans Signal Processing
- Aldana, Cioffi "Channel Tracking for Multiple Input, Single Output Systems using the EM Algorithm", ICC 2001.
- Aldana, Salvekar, Tellado, Cioffi, "MAP Noise Profile Matching for Multicarrier Systems", ICT 2001.
- Aldana, Salvekar, Tellado, Cioffi, "Accurate Noise Estimates in Multicarrier Systems", Fall VTC 2000.
- Salvekar, Aldana, Carvalho, Cioffi, "Crosstalk Profile Detection for use in Multiuser Detection", ICC 2001.
- Zeng, Aldana, Salvekar, Cioffi, "Crosstalk Identification in xDSL systems", IEEE Journal on Selected Areas of Communications.
- Salvekar, Aldana, Tellado, Cioffi, "Peak-to-Average Power Ratio Reduction for Block Transmission Systems in the Presence of Transmit Filtering", ICC 2001.
- Salvekar, Aldana, Tellado, Cioffi, "Channel Gain Change Detection and Channel Profile Selection in a Multicarrier System", Globecom 99.

Acknowledgment

- Advisor: Prof. Cioffi
- Associate advisor: Prof. Cox
- PhD Oral Committee: Prof. Tobagi and Prof. Gill
- Joice
- Family
- Wonderful Friends

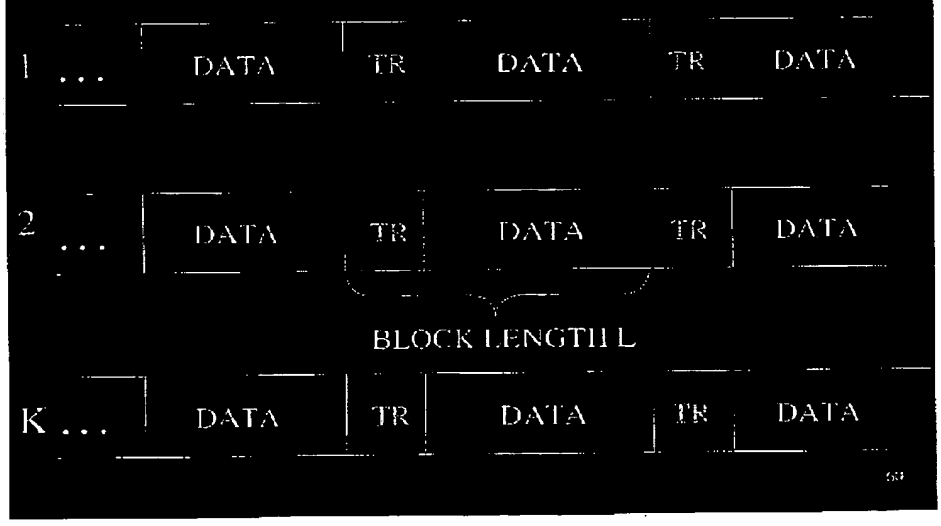




FSAN Model for NEXT sources

$$K_{NEXT} f^{\frac{3}{2}} \left(N_1 P_1(f)^{\frac{1}{0.6}} + N_2 P_2(f)^{\frac{1}{0.6}} \right)^{0.6}$$

Frame Structure for users 1 to K



System Model

A block of received data of length L can be collected to form:

$$\begin{bmatrix} Y^1 \\ Y^2 \\ \vdots \\ Y^L \end{bmatrix} = \begin{bmatrix} X_1^1 X_2^1 \cdots X_K^1 \\ X_1^2 X_2^2 \cdots X_K^2 \\ \vdots \\ X_1^L X_2^L \cdots X_K^L \end{bmatrix} \begin{bmatrix} H_1 \\ H_2 \\ \vdots \\ H_K \end{bmatrix} + \begin{bmatrix} N^1 \\ N^2 \\ \vdots \\ N^L \end{bmatrix}$$

$$\mathbf{Y = XH + N}$$

Problem: Find H and σ_n^2, but X is unknown!!

System Model

A block of received data of length L can be collected to form:

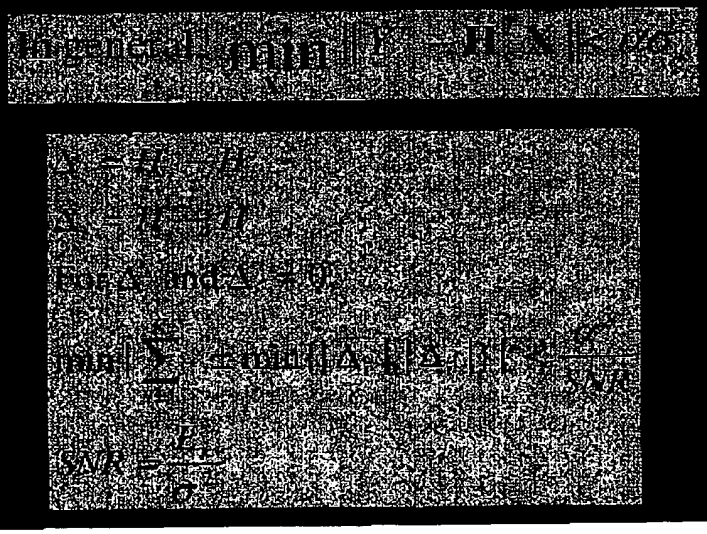
$$\mathbf{Y = XH + N}$$

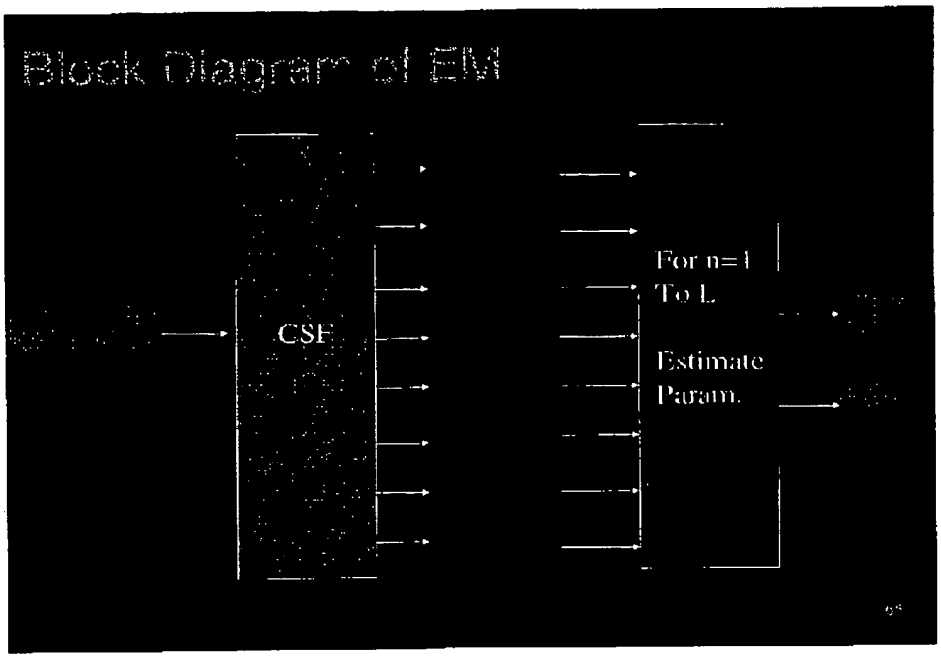
Problem: Find H and σ_n^2 but X is unknown!!

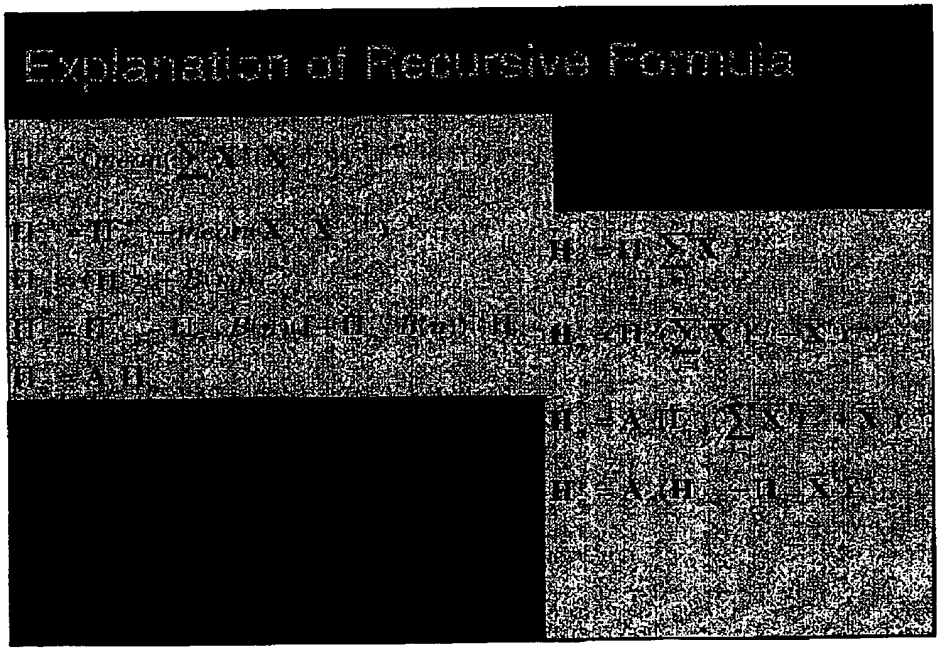
Review of Talwar Work

- ILSP Algorithm
  - Given H
  - Find LS estimate of X (since you have enough diversity)
  - Project onto Xhat
  - Using this Xhat find LS estimate of H and repeat.

EM Initial Condition for BPSK

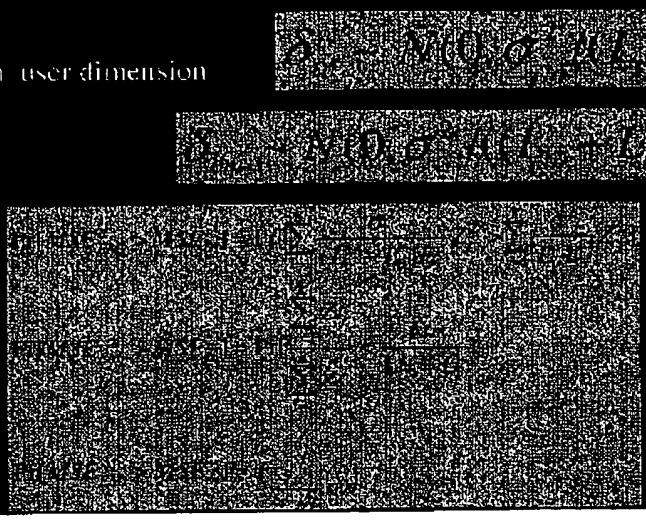




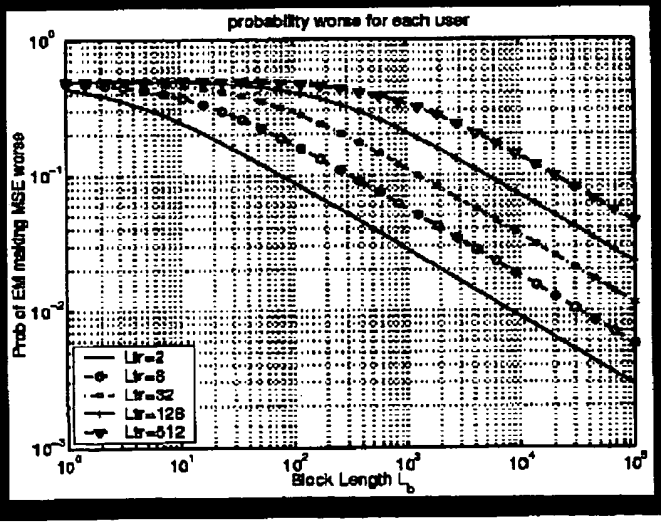


Explanation for F-distribution

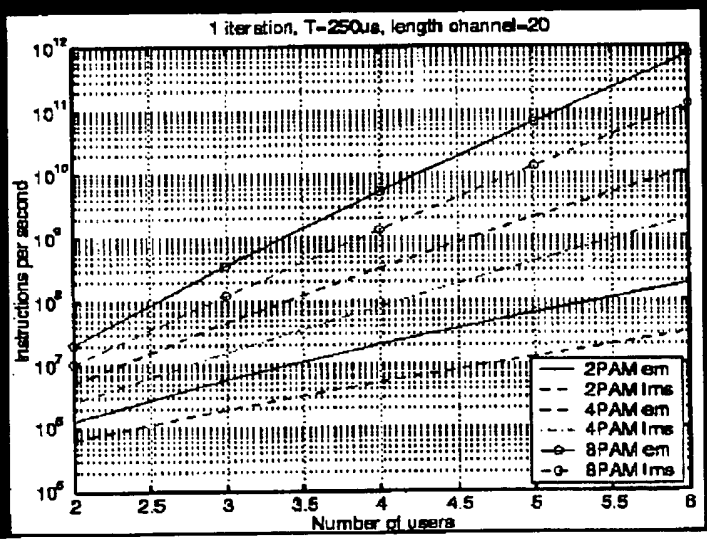
In each user dimension



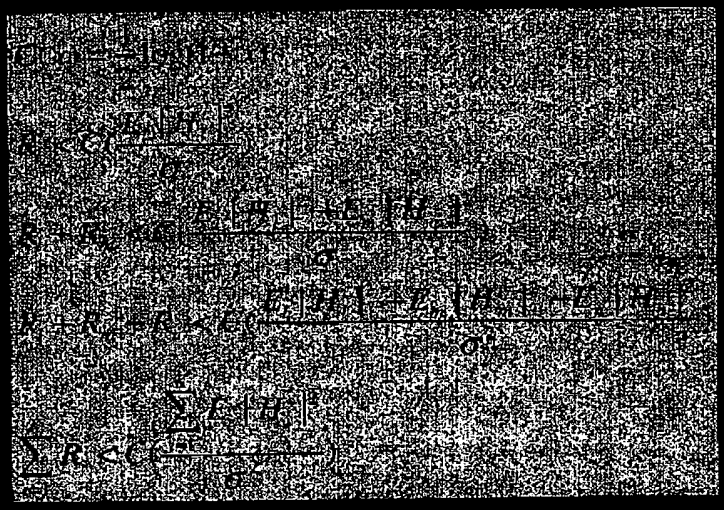
MSE Channel behavior for Lb varying

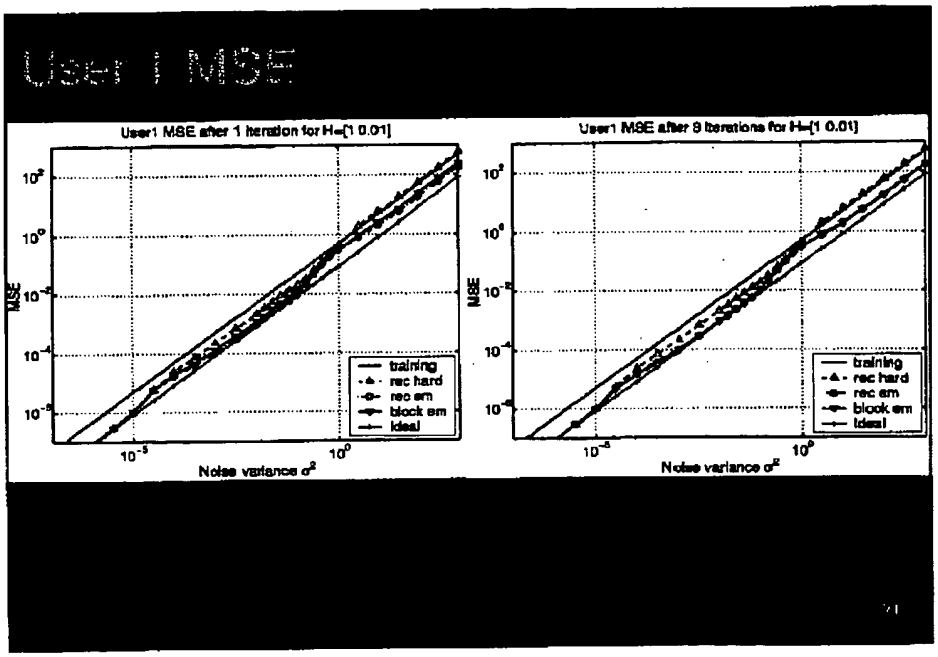


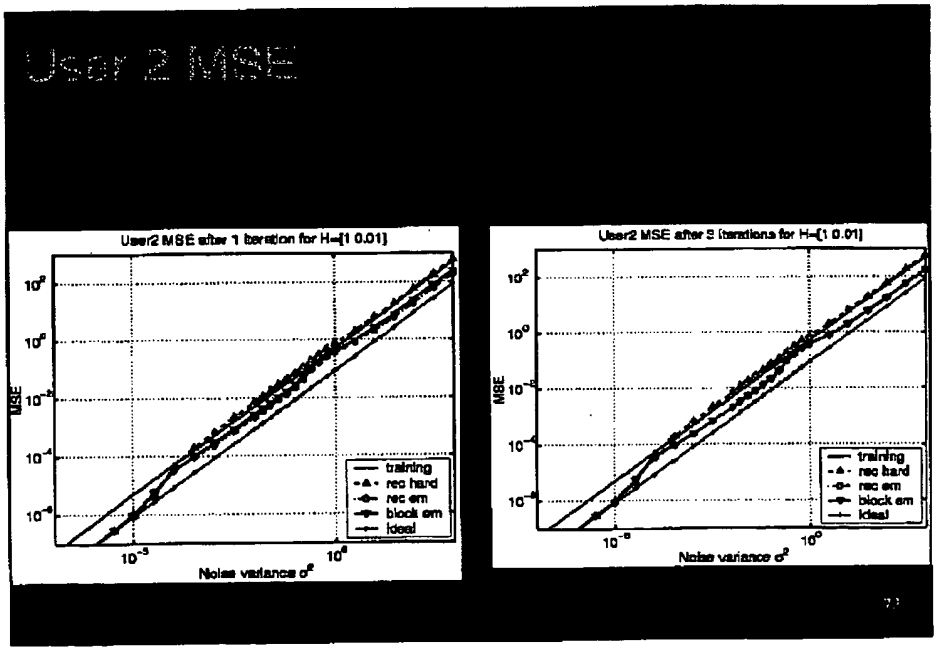
MIPS Plot for EM and LMS

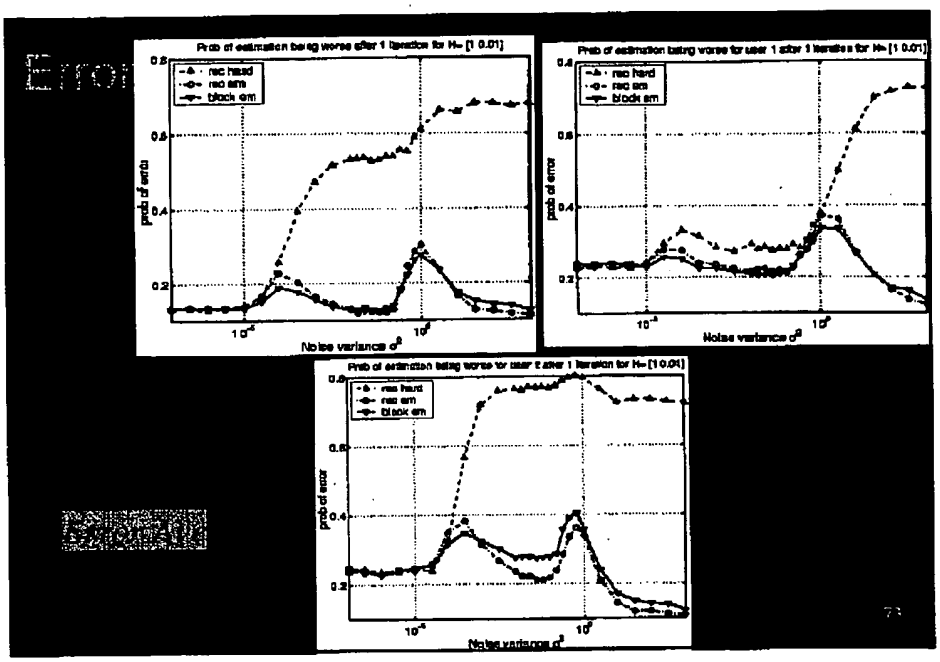


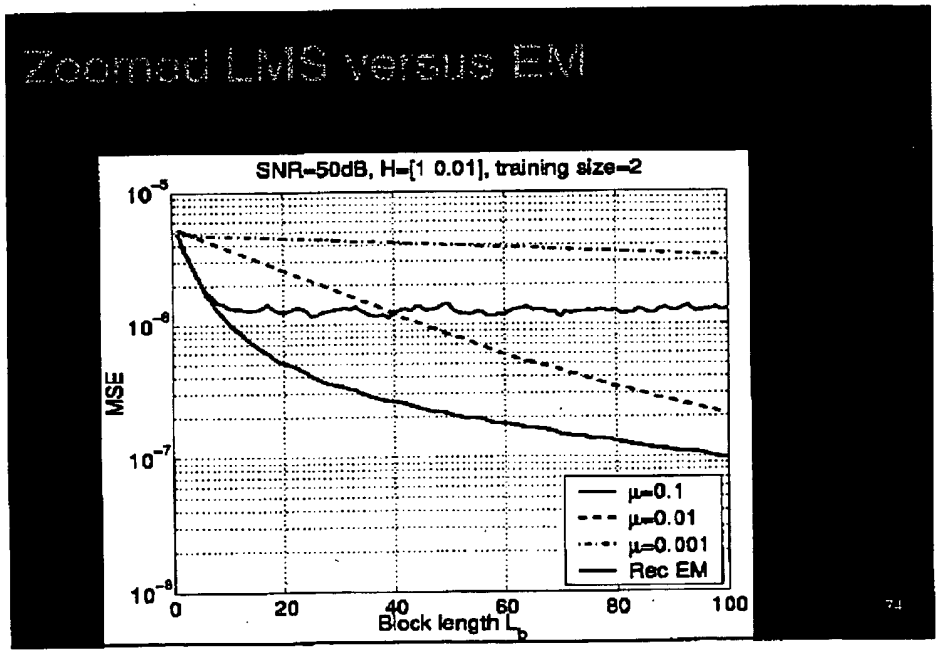
Gaussian MAC Capacity








Error
rec hard
rec em
block em
prob of error
Noise variance σ²


Zoomed LMS versus EM
SNR=50dB, H=[1 0.01], training size=2
MSE
Block length L_b
μ=0.1
μ=0.01
μ=0.001
Rec EM